SYNTHESIS AND CHARACTERIZATION OF CONJUGATED POLYMER NANOCOMPOSITE FOR ELECTROCHEMICAL APPLICATIONS

Final Synopsis submitted to fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

PHYSICS

Submitted By

Vijeth
Research Student

Under the supervision of

Prof. Devendrappa H
Professor

January 2020

Department of Physics,
Mangalore University, Mangalagangothri - 574 199
Mangalore, India

Synopsis

1. Introduction

With the rapid development of sustainable and renewable energy storage super capacitor (SC) devices with excellent specific capacitance and high energy density are rising various challenging issues due to the large-scale need for energy consumption [1-2]. Supercapacitors are one of the prominent energy storage devices among different energy storage devices due to their excellent energy density, long cycle life, fast charge-discharge capacity, and low maintenance cost with many advantages over batteries and also occupies vast scope of usage in various purposes [3]. The major demerit of the supercapacitor is that they have low energy density. Therefore, there is a need to enhance the energy density and potential window without losing the power density and cyclic stability. From the energy density relation $E=1/2CV^2$, by increasing the potential window (V) and specific capacitance (C_{sp}) one can enhance the energy density (E) of the supercapacitor.

An alternative approach to improve energy density is to develop hybrid electrochemical capacitors (so called asymmetric supercapacitors, or ASCs), which can also provide a wider operating potential window compared to symmetric supercapacitors. The use of redox active materials enhance substantially the energy density of supercapacitors due to their much higher specific capacitance 10–100 times more than carbonaceous materials. In case of aqueous-based supercapacitor devices, the voltage window of symmetric supercapacitor (SSC) is normally restricted up to 1.0 V but for asymmetric supercapacitor (ASC) it can be extended up to 2 V by using redox-active material cathode and activated carbon anode. The active carbon as anode and redox active material as cathode provide the high hydrogen and oxygen over potential respectively which enhances the potential window of aqueous-based ASC.

Mainly, supercapacitor can be categorized into electrical double layer capacitors (EDLCs) and pseudocapacitors (PC) based on the various charge storage mechanisms [4-5]. In general, energy storage process shows electrostatic behavior in EDLCs and separation of charges takes place at the interface of electrode and electrolyte. Conventional carbon-based materials like activated carbon, carbon nanotubes and graphene etc.,[6-8] are commonly used in EDLCs whereas in pseudocapacitors charge storage mechanism is faradic in nature i.e., electron charge transfer takes place between electrode and electrolyte [4]. Conducting polymers are preferred as a pseudocapacitor electrode materials because of their significant advantages in intrinsic flexibility and high electrical conductivity compared to other materials which makes them perfect candidates for high-performance flexible SCs. For this purpose, conducting polymers like polyaniline, polypyrrole, polythiophene [9-12] and metal oxides like RuO_2, MnO_2, NiO, Co_3O_4, ZnO and Al_2O_3 [13-17] are used to develop desirable and flexible storage devices.

Among various transition metal oxide pseudocapacitive materials, nickel oxide and aluminium oxide is considered as one of the most important electrode materials for high performance specific capacitor as it owes high specific capacitance, excellent stability, easy preparation, and various morphologies [18-20]. Nevertheless, the pure metal oxide suffers from relatively low conductivity and weak electrochemical stability which is incapable for the requirement of high specific capacitance supercapacitors [21]. To overcome these drawbacks and to improve the electrochemical performance of pseudocapacitive materials, several approaches such as nanostructure or hybridization with carbon based materials have been successfully developed. One of the emerging attractive concepts is to fabricate core-shell heterogeneous nanostructured nanocomposites. It has been demonstrated that electrode materials with core-shell nanostructure could gain high specific area, short ion diffusion path and increased active

sites. And also conductivity of the sample can be increased by incorporation of conducting additive material. Polypyrrole (PPy) is one of the most important conducting polymers which have been attracted as promising electrode material for supercapacitor applications due to its high specific capacitance, high conductivity and excellent mechanical properties [22-23]. Thus, PPy is widely used to increase the electrical conductivity as well as prevent the aggregation of active material [24-26]. The morphology of PPy such as nanosphere, nanotube and nanowire plays an important role in enhancement in the electrochemical properties [27-29]. Among these nanostructured material one dimensional polypyrrole nanotubes (PNTs) is attracted much because of fast electron transportation, relatively large surface area and easier accessibility of electroactive species through their porous network than nanorods and nanowires [30]. However, PNTs have poor cycle life compared with metal oxide since they swell and contract extensively on charging and discharging respectively, which leads to premature attenuation and decrease in specific capacitance [31]. To overcome this problem we have incorporated biopolymer called chitosan (CS). CS is one of the abundant natural biopolymer with superior characteristic such as high biocompatibility, high mechanical strength, low cost and excellent film forming ability. CS has been widely used in the field of biology and medicine, recently this material have been used extensively in electrochemistry especially, in the field of supercapacitors [32-33]. CS also possesses an inherent porosity and this porous template was utilised with KOH electrolyte which enhances the electrode properties for supercapacitor [34]. Taking into account the characteristic of metal oxide, CS and PNTs, it will be significant to decorate the metal oxide nanoparticle on to the outer surface of CS-PNTs in which metal oxide and CS protects PNTs from swelling and contrast during charging-discharging process. In addition, PPy core with hallow tubular structure served as a conductive and skeleton for

the nanocomposite which is beneficial for facilitating the electron collection and fast transport [35]. The combination of metal oxide with polythiophene (PTH) has proved a suitable supercapacitor electrode material. Recently, such composites were reported with exceptional chemical properties, large surface area, excellent electrical and thermal properties which made these materials suitable for supercapacitor electrode. Al_2O_3 is a unique material among the metal oxides that is used for supercapacitor because of its significantly larger potential window, low cost, and less toxicity which makes it usable as the electrode material. Also, recently Jalal Arjomandi et al. studied the high-performance capacitive behavior of polyaniline/Al_2O_3 nanocomposites. Therefore, recently many researchers paid much attention to achieve high-performance active electrode materials for supercapacitor. This current study would be allocated for developing a novel hybrid composite material for EDLC and pseudocapacitor.

2. Aims and objective of the present study

In order to address the research problem, the following research objectives were formulated.

1. To investigate the properties of nanostructured conducting polymer nanocomposite materials for supercapacitor applications.
2. Incorporation of metal oxide and quantum dot materials into nanostructured conducting polymer and evaluate their properties in supercapacitors.
3. To synthesize different nanocomposite by the chemical method and hydrothermal method.
    i. Nickel oxide incorporated with chitosan/polypyrrole nanotube nanocomposite
    ii. Chitosan/polypyrrole nanotube embedded with molybdenum disulfide quantum dot

iii. Camphor sulfonic acid surfactant assisted synthesis of polythiophene/ aluminium oxide nanocomposite

4. To evaluate the nanostructured conducting polymer nanocomposite for fabrication of different kind of supercapacitor such as flexible, high energy density all-solid-state symmetric supercapacitor (SSC), asymmetric supercapacitors (ASC) and also for hydrazine electrochemical sensors.

3. The brief sketch of the proposed thesis is as follows

The primary aim of the thesis is synthesis, characterization and electrochemical characterization of nanostructured conducting polymer nanocomposites and their application in the field of all-solid-state symmetric supercapacitor. Thesis contains six chapters; the first chapter includes the introductions to conducting polymers nanocomposite and their application in supercapacitor. The second chapter deals with various techniques involved synthesis, characterization of nanostructured conducting polymers and fabrication of supercapacitor. The third to sixth chapters discuss on the results obtained from analysis of experiments carried out to meet the research objectives. The third chapter includes the synthesis and characterization of Chitosan-Polypyrrole Nanotube incorporated with nickel oxide (CS-PNT/NiO) and their application in all-solid-state supercapacitors. The fourth chapter contains synthesis of MoS_2 quantum dot embedded with chitosan-polypyrrole nanotube (CS-PNT/MoS_2) for the application of All-solid state supercapacitors. The fifth chapter focuses on the polythiophene nanocomposites synthesized in presence of CSA surfactant for application in symmetric supercapacitor application and for hydrazine sensors. The sixth chapter emphasizes on flexible and high energy density asymmetric supercapacitor using polythiophene nanocomposites. The summary and epilogue are presented in the seventh chapter followed by the sections namely the references and list of research publications.

Chapter I: Introduction

The first chapter presents background information regarding the nanostructured conducting polymer and their applications in supercapacitor. A brief introduction on supercapacitor, their history, mechanism of charge storage, their applications, extensive literature survey, motivation to identify the research aims and objectives.

Chapter II: Materials, Characterization and Fabrications Method

This chapter describes about the synthesis procedure of nanostructured conducting polymer nanocomposites along with characterization techniques used to study the material properties such as structural, morphology, thermal and electrochemical properties. Fabrication of electrode material for supercapacitor device with different configuration and electrolyte are also described in this section.

Chapter III: Fabrication of All-Solid-State Symmetric Supercapacitor using CS-PNT/NiO Core Shell Nanostructure

The present chapter gives a brief idea of Chitosan-polypyrrole nanotube incorporated with nickel oxide core shell nanostructure using soft template method with Methyl Orange and ferric chloride as template. In present work a novel cost effective NiO nanoparticle incorporated with CS-PNTs core-shell nanostructure (NiO/CS-PNTs) in which chitosan-polypyrrole nanotube is grown as core and spherical shaped NiO nanoparticle as shell material and investigated their potential applications for all-solid-state symmetric supercapacitor applications. For comparative studies we have synthesised pure PNTs and NiO nanoparticle incorporated PNTs (NiO/PNTs) core shell nanostructure and characterised using different characterising techniques. The NiO/CS-PNTs core-shell nanocomposite exhibits a low charge transfer resistance (1.01 Ω) and high specific capacitance of 934.11 F/g which is much higher than NiO/PNTs (581.77 F/g) and PNTs (337.44 F/g) at current density of 1 A/g. Besides, all-solid-state symmetric supercapacitor (SSC) is fabricated with NiO/CS-

PNTs shows high energy density of 62.94 Wh Kg^{-1} at high power density of 458.70 W kg^{-1} and 3669.56 W kg^{-1} at energy density of 25.21 Wh Kg^{-1} and also it exhibits high cyclic stability with capacitance retention of 88.91 % even after 5000 cycles. The remarkable performance of NiO/CS-PNTs is mainly attributed to the good electrical conductivity of PNTs and 1D core-shell nanostructures. The results demonstrate that NiO/CS-PNT core-shell nanostructure is a promising electrode material for supercapacitors.

Chapter IV: MoS_2 Quantum Dot incorporated with Chitosan mediated Polypyrrole Nanotube for All-Solid-State Symmetric Supercapacitor

In this chapter we have synthesized MoS_2 quantum dot using hydrothermal method which is embedded on the chitosan/polypyrrole nanotube (CS-PNT). Here CS-PNT acts as core material and MoS_2 act as shell material to form core-shell nanostructure. Taking into account the characteristic of MoS_2, CS and PNT, it will be significant to decorate the MoS_2 quantum dot on to the outer surface of CS-PNT in which MoS_2 and CS protects PNTs from swelling and contrast during charging-discharging process. In addition, PPy core with hallow tubular structure served as a conductive and skeleton for accommodate the nanocomposite which is beneficial for facilitating the electron collection and fast transport. The electrochemical characterization shows CS-PNT/MoS_2 core shell nanostructure exhibits high specific capacitance of 793.25 F/g which is much higher compared to PNT/MoS_2 (395 F/g) at current density of 1 A/g in three electrode system. Moreover, all-solid-state symmetric supercapacitor fabricated using CS-PNT/MoS_2 shows high energy density 54.46 Wh Kg^{-1} at power density of 499.97 Wkg^{-1} and high power density of 4786.45 Wkg^{-1} at energy density of 30.51 Wh Kg^{-1}. This results show the great potential of CS-PNT/MoS_2 core-shell nanostructure as high performance electrode material for supercapacitors.

Chapter V: Camphor Sulfonic Acid Assisted Polythiophene Nanocomposite for All-Solid State Symmetric Supercapacitor

This chapter comprises of cost-effective method with anionic surfactant- camphor sulfonic acid assisted synthesis of spherical shaped polythiophene/Al_2O_3 (PTCA) composites by chemical polymerization of thiophene. The symmetric supercapacitor (SSC) was fabricated with PTCA composite, and its energy storage capabilities in PVA-KOH gel electrolyte were studied. An electrochemical study showed that polythiophene/50%Al_2O_3 (PTCA5) composite electrode exhibits the highest gravimetric specific capacitance of 780.40 Fg^{-1} at 0.5 Ag^{-1} in three electrode system. Subsequently, the all-solid-state symmetric supercapacitor (SSC) fabricated using PTCA5 electrode achieved a specific capacitance of 472.8 Fg^{-1} at 1 Ag^{-1} using PVA-KOH gel as an electrolyte. Moreover, SSC showed excellent cyclic performance with 90.54% capacitance retention of its initial capacitance even after 5000 cycles. Additionally, a superior specific energy density of 58.04 $Whkg^{-1}$ was obtained at a specific power density of 533.02 Wkg^{-1} for the same. This high potential and energy density device find its application in the low-cost energy storage devices. Encouragingly, the fabricated SSC is utilized to light a commercial red LED effectively to validate the real usage.

Chapter VI: Flexible and High Energy Density Solid State Asymmetric Supercapacitor based on Polythiophene Nanocomposite and Efficient Electrochemical Hydrazine Sensor

In this chapter we have focused on enhancing the power density, energy density, and life cycle of supercapacitors. The main objective of the work is to identify the highly efficient device with low cost, large scale production, environmental friendly anode and cathode electrodes. We have fabricated a flexible solid-state ASC using polythiophene /Al_2O_3 nanocomposite as an anode electrode and a charcoal-based cathode electrode. The highest specific capacitance (C_{sp}) of the PTHA electrode was found to be 554.03 F/g at a current density (CD) of 1 A/g and that of the charcoal electrode was 374.71 F/g at 1.4 A/g,

measured using three electrode system. The maximum C_{sp} obtained for the assembled PTHA//Charcoal asymmetric supercapacitor (ASC) was 265.14 F/g at 2 A/g. It also showed high energy density of 42.0 Wh/kg at power density of 735.86 W/kg and capacitance retention of 94.61% even after 2000 cycles. Moreover, it is worth mentioning that the asymmetric device used to glow light emitting diode (LED) for more than 15 minutes. This PTHA//charcoal ASC also possesses stable electrochemical properties in different bending position and hence it finds a promising application in flexible, wearable and portable energy storage electronic devices.

The electrochemical sensing of hydrazine by PTH and CSA-PTHA was investigated using different techniques such as cyclic voltammetry and amperometric response. Comparing with PTH modified GCE; CSA-PTHA modified GCE shows a superior sensing performance leading to remarkable sensitivity of 0.285 μA $\mu M^{-1}cm^{-2}$ and a very low limit of detection (LOD) of 0.18 μM at S/N = 3 for wide linear range of hydrazine concentration from 10 μM to 90 μM with a correlation coefficient R^2=0.99668. Also, the performance of CSA-PTHA modified GCE electrode is comparable or even better than that of the other reported functional materials for hydrazine detection. Hence, our results reveal that the compositing of conducting polymer with metal oxide could provide an efficient way to fabricate advance and economic electrochemical sensors.

Chapter VII: Summary and Future work

Summarizes the findings of the present investigations and the scope for further studies in this field.

References

[1] M. Li, J. P. Cheng, J. Wang, F. Liu, X. B. Zhang, Electrochim. Acta, 2016, **206,** 108-115

[2] W. Wang, Q. Hao, W. Lei, X. Xia, X. Wang, RSC Adv. 2012, **2,** 10268-10274

[3] L. L. Zhang, X. S. Zhao, Chem. Soc. Rev. 2009, **38,** 2520-2531

[4] P. Simon and Y. Gogotsi, Nat. Mater, 2008, **7**, 845.

[5] G. Wang. L. Zhang and J. Zhang, Chem. Soc. Rev, 2012, **41,** 797-828.

[6] S. Bose, T. Kuila, A. K. Mishra, R. Rajasekar and N.H. Kim, J. Mater. Chem., 2012, **22**, 767-784.

[7] L. L. Zhang and X.S. Zhao, Chem. Soc. Rev., 2009, **38,** 2520-2531.

[8] C. Liu, Z. Yu, D. Neff, A. Zhamu and B. Z. Jang, Nano Lett., 2010, **10**, 4863-4868.

[9] R. Hu, J. Zhao, G. Zhu and J. Zheng, Electrochim. Acta, 2018, **261**, 151-159.

[10] R. Yuksel, E. Alpugan and H. E. Unalan, Org. electron., 2018, **52**, 272-280.

[11] C. Fu, H. Zhou, R. Liu, Z. Huang, J. Chen and Y. Kuang, Mater. Chem. Phys., 2012, **132**, 596-600.

[12] V. Subramanian, S. C. Hall, P. H. Smith and B. Rambabu, Solid State Ionics, 2004, **175**, 511-515.

[13] Xu, M. Wen, W. Jia, S. J. Bao, Z. Su and B. Dong, Electrochim. Acta, 2010, **54**, 5117-5122.

[14] W. Yang, Z. Gao, J. Ma, X. Zhang, J. Wang and J. Liu, J. Mater. Chem. A, 2014, **2,** 1448-1457.

[15] K. Deori, S. K. Ujjain, R. K. Sharma and S. Deka, ACS Appl. Mater. Interfaces, 2013, **5**, 10665-10672.

[16] J. Wang, Z. Gao, Z. Li, B. Wang, Y. Yan, Q. Liu and Z. Jiang, J. Solid State Chem., 2011, **184**, 1421-1427.

[17] J. Arjomandi, J. Y. Lee, R. Movafagh, H. O. B. Moghanni and M. H. Parvin, J. Electro. Anal. Chem., 2018, **810**, 100-108

[18] Liang, Kun, Xianzhong Tang, and Wencheng Hu. Journal of Materials Chemistry, 2012, **22**, 11062-11067.

[19] Yang, Shubin, Xilin Wu, Changlun Chen, Huanli Dong, Wenping Hu, and Xiangke Wang. Chemical Communications, 2012, **48**, 2773-2775.

[20] Rai, Prabhakar, Ji-Wook Yoon, Hyun-Mook Jeong, Su-Jin Hwang, Chang-Hoon Kwak, and Jong-Heun Lee. Nanoscale, 2014, **6**, 8292-8299.

[21]Yan, Minglei, Yadong Yao, Jiqiu Wen, Lu Long, Menglai Kong, Guanggao Zhang, Xiaoming Liao, Guangfu Yin, and Zhongbing Huang. ACS applied materials & interfaces, 2016, **8**, 24525-24535.

[22] Snook, Graeme A., Pon Kao, and Adam S. Best. Journal of power sources, 2011, **196**, 1-12.

[23] Meng, Qiufeng, Kefeng Cai, Yuanxun Chen, and Lidong Chen. Nano Energy 2017, **36**, 268-285.

[24] Wang, Jian-Gan, Ying Yang, Zheng-hong Huang, and Feiyu Kang. Electrochimica Acta, 2014, **130**, 642-649.

[25] Lee, Jun Seop, Dong Hoon Shin, and Jyongsik Jang. Energy & Environmental Science 2015, **8**, 3030-3039.

[26] J. Hu, M. Li, F. Lv, M. Yang, P. Tao, Y. Tang, H. Liu, Z. Lu, J. Power Sources 2015, **294**, 120 – 127.

[27] Zhang, Jing, Yao Yu, Lin Liu, and Yue Wu. Nanoscale, 2013, **5**, 3052-3057.

[28] Biswas, Sanjib, and Lawrence T. Drzal. Chemistry of Materials, 2010, **22**, 5667-5671.

[29] Liu, Jianhua, Junwei An, Yuxiao Ma, Mengliu Li, and Rongbao Ma. Journal of the Electrochemical Society, 2012, **159**, A828-A833.

[30] T.Y. Huang, C.W. Kung, H.Y. Wei, K.M. Boopathi, C.W. Chu, K.C. Ho, J. Mater. Chem. A, 2014, **2**, 7229-7237

[31] Chen, Yong, Guiying Kang, Hui Xu, and Long Kang, Synthetic Metals, 2016, **215**, 50-55.

[32] Hao, Pin, Zhenhuan Zhao, Yanhua Leng, Jian Tian, Yuanhua Sang, Robert I. Boughton, C. P. Wong, Hong Liu, and Bin Yang. Nano Energy, 2015, **15**, 9-23.

[33] Hassan, Sameh, Masaaki Suzuki, and Ahmed Abd El-Moneim. Journal of Power Sources, 2014, **246**, 68-73.

[34] Hao, Pin, Zhenhuan Zhao, Yanhua Leng, Jian Tian, Yuanhua Sang, Robert I. Boughton, C. P. Wong, Hong Liu, and Bin Yang. Nano Energy, 2015, **15**, 9-23.

[35] He, Yibo, Yonglong Bai, Xiaofan Yang, Jinyang Zhang, Liping Kang, Hua Xu, Feng Shi, Zhibin Lei, and Zong-Huai Liu. Journal of Power Sources, 2016, **317**, 10-18.

List of Journal Publications

1. A paper entitled *"Flexible all Solid State Asymmetric Supercapacitor Based on Polythiophene Nanocomposites/Charcoal with High Energy Density"* in ***RSC Advances,*** 2018, 55(8), 31414-31426. **Vijeth H,** Ashokkumar SP, Yesappa L, Niranjana M, Vandana M, Devendrappa H*. https://doi.org/10.1039/C8RA06102E

2. A paper entitled *"Camphor sulfonic acid assisted synthesis of polythiophene composite for high energy density all-solid-state symmetric supercapacitor"* in ***Journal of Materials Science: Materials in Electronics***, 2019
H. Vijeth, S.P. Ashokkumar, L. Yesappa, M. Niranjana, M. Vandana, H. Devendrappa* https://doi.org/10.1007/s10854-019-01060-2

3. A paper entitled *"Camphor Sulfonic Acid Surfactant Assisted Polythiophene Nanocomposite for Efficient Electrochemical Hydrazine Sensor"* in ***Material research expresses (IOP).*** **H. Vijeth,** L Yesappa, SP Ashokkumar, Vandana M, H Devendrappa*. 10.1088/2053-1591/ab5ef5

4. A paper entitled *"Hybrid Core-Shell nanostructure made of Chitosan incorporated Polypyrrole Nanotubes decorated with NiO for All-Solid-State Symmetric Supercapacitor Application"* in ***Electrochemical Acta*** (Revision submitted).
H. Vijeth, L Yesappa, SP Ashokkumar, Vandana M, H Devendrappa*

5. A paper entitled *"Modified Thermal, Dielectric, and Electrical Conductivity of PVDF-HFP/LiClO4 Polymer Electrolyte Films by 8 MeV Electron Beam Irradiation"* in ***ACS Omega,*** **3,** 2018, 14188–14200. L Yesappa, M Niranjana, SP Ashokkumar, **H Vijeth**, Ganesh Sanjeev, H Devendrappa
https://doi.org/10.1080/10420150.2018.1486840

6. A paper entitled *"Surfactant-assisted Surface Morphology and Thermal Properties of Polythiophene Composites,"* **AIP Conference Proceedings,** 1849, 020043 (2017). **Vijeth H,** Niranjana M, Yesappa L, Ashokkumar SP, Sharanappa Chapi, Raghu S, Devendrappa H. http://dx.doi.org/10.1063/1.4984190

7. A paper entitled "*Polythiophene nanocomposites as a high-performance electrode material for supercapacitor application*" **AIP conference proceedings**, 1942, 140017 (2018). **Vijeth H**, Niranjana M, Yesappa L, Ashokkumar SP, Devendrappa H*
https://doi.org/10.1063/1.5029148

8. A paper entitled "*Investigation on structural, optical and electrical properties of polythiophene-Al2O3 composites*" **AIP conference proceedings,** 1953, 050008 (2018). **Vijeth H,** Niranjana M, Yesappa L, Ashokkumar SP, Devendrappa H*
https://doi.org/10.1063/1.5032663

9. A paper entitled "*Photocatalytic degradation of methylene blue and Rhodamine B using polythiophene nanocomposites under visible and UV light*" **AIP conference proceedings,** 2115, 030536 (2019). **H Vijeth**, SP Ashokkumar, L Yesappa, M Vandana, H Devendrappa*. https://doi.org/10.1063/1.5113375

10. A paper entitled *"Localized polarons in situ synthesized polyaniline nanocomposite improve the morphology and the thermal and electrical conductivity"* in ***RSC Advances,*** 2016, **6**, 115074-115084. M. Niranjana, L. Yesappa, S. P. Ashokkumar, **H. Vijeth**, S. Raghu and H. Devendrappa. https://doi.org/10.1039/C6RA24137A

11. A paper entitled *"Investigation of the Structure, Optical and Electrical Properties of Lithium Perchlorate Doped Polyaniline Composite: Aloe Vera Used as a Bio-Plasticizer"* in ***Journal of Electronic Material***, 2017, 1-12. L. Yesappa, M. Niranjana, SP Ashokkumar, **H.Vijeth,** C. Sharanappa, S Raghu, H Devendrappa. https://doi.org/10.1007/s11664-017-5724-1

12. A paper entitled "Optical *properties and ionic conductivity studies of an 8 MeV electron beam irradiated poly (vinylidene fluoride-co-hexafluoropropylene)/LiClO 4 electrolyte film for optoelectronic applications*" in **RSC Advances**, 2018, 8, 15297-15309. L Yesappa, M Niranjana, SP Ashokkumar, **H.Vijeth**, M Basappa, Jishnu Dwivedi, VC Petwal, S Ganesh, H Devendrappa. https://doi.org/10.1039/C8RA00970H

13. A paper entitled "*Effect of electron beam irradiation on structure, morphology, and optical properties of PVDF-HFP/PEO blend polymer electrolyte films*" in ***Journal of Radioanalytical and Nuclear Chemistry.*** L. Yesappa, S. P. Ashokkumar, **H. Vijeth**, M. Basappa, Sanjeev Ganesh, H. Devendrappa. https://doi.org/10.1007/s10967-019-06466-0L

14. A paper entitled "*Characterization, Electrical Conductivity and Electrochemical Performance of Polyaniline-LiClO4-CuO Nanocomposite for Energy Storage Applications*" in **Polymer-Plastics Technology and Engineering (Taylor & Francis),** 2018, 1-13. L Yesappa, M Niranjana, S Ashokkumar, **H Vijeth**, S Raghu, H Devendrappa. https://doi.org/10.1080/03602559.2018.1466175

15. A paper entitled *"Increased porous morphology and thermal degradation of electron beam-irradiated PVDF-HFP/LiCLO4 polymer electrolyte"* in **Radiation Effects and Defects in Solids (Taylor & Francis),** 2018, 601-607. L Yesappa, M Niranjana, SP Ashokkumar, **H Vijeth**, Ganesh Sanjeev, H Devendrappa https://doi.org/10.1080/10420150.2018.1486840

Foreign visit:

1. Participated & presented an article entitled *"Nickel oxide nanoparticle incorporated polypyrrole nanocompo-site for supercapacitor application"* in the 5th edition of Nanotech France 2019 International Conference and Exhibition **NANOTECH FRANCE 2019** held at **Paris - France** during 26-28th June 2019. **Vijeth H**, Yesappa L, Ashokkumar SP, Vandana M, Devendrappa H.

Conferences and Workshops:

1. Participated & presented an article entitled *"Influence of Nickel Oxide Nanoparticle on the Structural,Electrical and Dielectric Properties of Polypyrrole Nanocomposite"* in ICABS-2019 Organized by GDC Memorial College Bahal, Bhiwani Haryana, India during 7-9th February 2019.
   Vijeth H, Yesappa L, Ashokkumar SP, Vandana M, Devendrappa H.

2. Participated & presented an article entitled *"Photocatalytic Degradation of Methylene Blueand RhodamineB using Polythiophene Nanocomposites under Visible and UV light"* in DAE Solid State Symposium 2018 Organized by Guru Jambeshwar University of Science & Technology, Hisar, Haryana, India during 18-22th December 2018.
   Vijeth H, Yesappa L, Ashokkumar SP, Vandana M, Devendrappa H.

3. Participated & presented an article entitled *"Surfactant-assisted Surface morphology and Thermal Properties of Polythiophene Composites"* in OPTICS-2017 Organized by NIT Calicut, Kerala, India during 9-11th January 2017.
   Vijeth H, Niranjana M, Yesappa L, Ashokkumar SP, Sharanappa Chapi, Raghu S, Devendrappa H.

4. Participated & presented a paper entitled "Polythiophene nanocomposites as high-performance electrode material for supercapacitor application" in DAE symposium - 2017 Organized by BARC Mumbai, India during 26-30th December 2017.
   Vijeth H, Niranjana M, Yesappa L, Ashokkumar S P, Devendrappa H*

5. Participated & presented a paper entitled "*Investigation on Structural, Optical and Electrical Properties of Polythiophene-Al_2O_3 Composites*" in ICC -2017 Organized by Govt. Engg College Bikaner Rajasthan, India during 24-25th November 2017.
   Vijeth H, Yesappa L, Niranjana M, Ashokkumar S P, Devendrappa H*

6. Participated & presented a paper entitled *"Structural and Surface Morphology of Methylene Red Dye-doped PMMA Films"* in RAMSB-2018 organized by Department of Physics, Mangalore University, Mangalore India during 23-25th January 2018.
   Vijeth H, Yesappa L, Niranjana M, Ashokkumar S P, Vandana M, Devendrappa H*

Workshops:

SL. No	Organization	Period		Details of Training/ Project undertaken
		From	To	
1	CENSE Indian Institute of Science, Bangalore.	1st December 2016	9th December 2016	INUP Hands-on Training Workshop on "**Photovoltaic and Micro and Nano Characterization Techniques"**
2	Dept. of physics, NIT Calicut Kerala	2nd November 2016	9th November 2016	GIAN Workshop on **"International Winter Course on Organic Solar cells: Principles and Practices."**

3	Madurai Kamaraj University Tamilnadu	29th May 2017	10th June 2017	GIAN workshop on **"Solar cells, materials, and modeling."**
4	CARRT Mangalore University	27th February 2017	6th March 2017	GIAN workshop on **"Nanofibers and their application."**
5	Department of Physics, Mangalore University, Konaje.	11th October 2018	17th October 2018	GIAN workshop on **"Nanostructure based wide band gap semiconductor for sensor application"**
6	Dept. of Chemistry, Mangalore University, Konaje.	03rd December 2018	08th December 2018	GIAN workshop on **"Multifunctional Advanced Nanomaterials and their Applications"**

Research Guide

Research student